Improving Energy Efficiency of Femtocell Network with Limited Backhaul Capacity

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Abstract — *Deployment count of femtocell base stations has already exceeded the count of macrocell base stations and it is expected to increase further. Deployment of femtocell comes with both capital and operational expenditure from operators' side. In order to facilitate dense femtocell deployment, especially in rural and remote areas, the availability of wired backhaul and round the clock grid power are major concerns. In this paper, we suggest an energy efficient cell selection scheme for femtocell based cellular network considering the energy consumption and capacity constraint at the backhaul links. Our proposed cell selection scheme improves the energy efficiency of the femtocell network by not only considering the energy consumption at base stations but also at the backhaul links. Obtained results are verified using extensive simulations.*

Keywords — *Femtocell, cell selection schemes, energy efficiency, performance evaluation, backhaul constraint.*

I. Introduction

Use of low power base stations such as microcell, picocell, relays, and hotspots have proved to be an cost effective solution for increasing network coverage and capacity. These small base stations facilitate efficient spacial reuse of available wireless spectrum thereby improving system spectral efficiency [1]. However, it has been seen that even with dense deployments of these low power nodes, operators are still unable to satisfy increase mobile data demands. Another interesting thing to note that most of these data demands are originating form indoor users. Additionally, due to wall penetration loss, these users get worst signal quality.

To overcome this indoor data demand problem, cellular operators suggested deployment of miniature base stations inside homes/offices. These base stations are commonly known as Femtocell or Femto Access Points (FAPs) [2]. Femtocell are low cost low power devices, very similar to WiFi access point but dissipates signals in cellular operators' licensed spectrum. These femtocell remains connected to cellular core network via wired/wireless backhaul. It has been seen that even unplanned dense deployment of femtocells in home/office environment helps improving network capacity manyfold by eliminating wall loss for the scenario. Not only that, it also helps improving network coverage and energy efficiency in a cost effective manner.

Use of femtocell to extend cellular coverage in rural and remote areas is a promising solution. However, considering operators perspective, higher deployment costs and low revenues are major challenges. Additionally, maintenance cost due to electricity consumption in core network and backhaul links is another issue. The energy consumption mostly depends on load at base stations and in turn the cell selection scheme used to associate mobile users to base stations. Most widely used scheme is based on Reference Signal Received Power (RSRP) where users are assigned to base stations having highest received signal power [3]. However, such techniques may not be optimal in terms of users' Quality of Service (QoS). Another interesting approach is the use of cell biasing for cell selection [4]. Cell biasing gives more priority to femtocell for user association than macrocell. This helps improving user count in femtocell by offloading users from expensive macrocells. Considering users' perspective, expected bitrate based association is suggested in [5, 6]. These techniques try to associated users to base stations based on the expected bitrate they might receive. Expected bitrate based association performs better then RSRP and bias based schemes because it incorporates scheduling opportunities at base stations. All of these schemes do not incorporate the backhaul energy consumption into cell selection criteria. Since energy consumption in backhaul links is considerable, it is of interest to look into their energy efficiency measures.

To the best of our knowledge, there do not exist any energy efficiency cell selection schemes with backhaul constraint in the literature. Our previous work in [7] have analysed the energy efficiency performance of various cell selection schemes with backhaul constraint. In this paper, we for the first time propose a cell selection scheme that considers backhaul energy consumption into cell selection criteria [8]. For performance evaluation, we have considered it with Max RSRP and expected bitrate based cell selection schemes for system capacity, energy consumption and energy efficiency.

Rest of the papers is organizes as follows. In section II, we get an overview of femtocell architecture. Section III discusses various cell selection schemes for femtocell based cellular network, along with their advantages and limitations. Section IV explains the energy consumption model of two tier macrocell-femtocell network along with backhaul energy consumption analysis. Section V we propose our energy efficiency cell selection scheme for femtocell network with backhaul constraint. Finally, we conclude our work in section VI with direction for future research.

II. Introduction to Femtocell Network

Femtocell or Femto Access Points (FAPs) are small, low power base stations deployed inside users' homes/offices to provide improved coverage and bitrate. Femtocell maintains connectivity with cellular core network via wired broadband/ADSL line [2]. In this way, no additional infrastructure such as wired backhaul is required as femtocell can use existing telephone/Internet line for communication. The inherent low transmit power capability of femtocell allow efficient spatial reuse of available wireless spectrum and improve overall spectrum efficiency. Figure 1 represents the basic architecture of femtocell network.

Femtocell differs from other small cell base stations (Microcell and picocell) as they are not deployed by operators to maintain specification requirements. These devices are sold as a secondary infrastructure to users who wish to have better bitrate and coverage inside their home at the cost of few extra dollars in monthly rental. Additionally, unlike other small cells, femtocell allows only registered users to get associated with it. Hence, the user who paid for the device and monthly rental will get benefits of its deployment. Lastly, since femtocell are user owned devices, they can placed anywhere and even can be turned off when required. The biggest advantage of using femtocell over WiFi is their capability to self-organize [9]. Femtocell are able to perform necessary synchronization/handover efficiently, hence able to efficiently handle intra and cross-tier interference. Recent research in the field of femtocell focuses on improving energy efficiency of femtocell networks, specially for sparsely populated rural environment [10]. Since femtocell are low power low cost devices, they have a potential to improve coverage in the far-fetched areas. Additionally, use of solar power is suggested in order to reduce dependency on grid power. The major challenge in femtocell deployments is the availability of backhaul links. These backhaul links accounts for additional capital and operational expenditure from operators' side. Hence, a cost and energy efficient backhaul sharing scheme is desirable to make dense deployments of femtocell network feasible in near future.

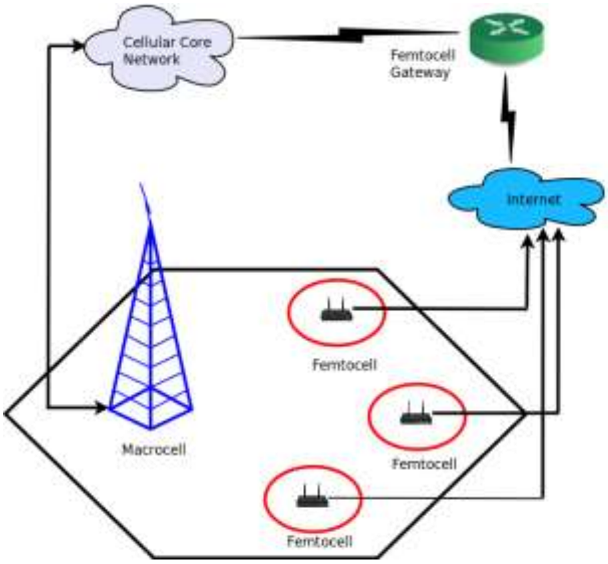

Fig. 1: Femtocell Architecture

III. System Model

Our system model consists of a Macrocell Base Station (MBS) deployed in a region with low power Femto Access Points (FAPs). FAPs operate in open access mode and can serve any mobile User Equipment's (UEs) under their coverage. UEs are distributed uniformly in the simulation region. The bitrate request of UE u is represented by β_u . Total available bandwidth is divided into N subchannel, each of width W Hz. Flat fading channels are considered to have similar characteristics over the long run. The set of backhauls links in the system is represented by the set B. Each FAP routes its data to core network using one or more backhaul links in the network. The maximum capacity of backhaul link k is represented by $B(k)$.

A. Channel model and received bitrate

Let P_u^b be the subchannel transmit power of base station b for UE u. The Signal to Interference plus Noise Ratio (SINR) of UE u can be calculated as,

$$\gamma_u^b = \frac{P_u^b \Gamma_u^b}{\sum P_u^{b'} \Gamma_u^{b'} + N_0}$$

where Γ_u^b is the channel gain from base station b to UE u. N_0 is the Gaussian noise figure. Based on the SINR, the received bitrate at UE u from base station b can be calculated using Shannon theorem as follows [11],

$$B_u^b = N_u * W * \log_2\left(1 + \gamma_u^b\right)$$

where N_u is the number of subchannels assigned to UE *u* base station *b*.

IV. Energy consumption model

In this section we present the energy consumption model of MBS and FAPs. Additionally, we also look into the energy consumption associated with backhaul connecting FAPs to cellular core network.

1) Energy Consumption: Energy consumption of a base station (MBS or FAP) is assumed to be load dependent with some fixed zero-load energy loss. Higher the load at a base station, more transmit power will be required to serve its UEs. This consequently results in higher energy consumption. The total energy consumption of base station *b* can be calculated as [12, 13],

$$E_b = E_b^0 + \Phi T_m / \rho_{PA} + CL_b$$

Where E_b^0 represents the zero load energy consumption of base station accounting for battery backup and power supply. Φ, and ρ_{PA} represent power amplifier efficiency and signal processing overhead, respectively. Here T_m is total input power to transmitting antenna obtained by summing up transmit power of all the subchannels in use. CL_b represents the cooling loss which is taken to be zero for FAPs.

2) Backhaul Energy Consumption: In our system model, we consider that each FAP is connected to core network with a dedicated wired backhaul. Each backhaul has a limited capacity and energy consumption in a backhaul depends upon the amount of data traffic passes through it. Let BH_b^0 be the idle mode energy consumption of backhaul connecting femtocell *b* to the core network. Then, the energy consumption of backhaul can be represented as [14],

$$BH(b) = BH_b^0 + f(\Omega_b)$$

where Ω_b represents the total downlink throughput that passes through the backhaul connecting femtocell *b*. Function f(.) is the step function which maps the downlink throughput to its equivalent energy consumption.

4) Energy Efficiency: To compare energy efficiency performance of different cell selection schemes, we take Energy Consumption Rating (ECR) as performance metric [15]. ECR is the ratio of total energy consumed to total system capacity. ECR can be calculated as,

$$ECR(watts/Mbps) = \frac{Energy\ Consumption}{System\ Capacity}$$

Hence, lower the ECR, more energy efficient the system will be.

V. Cell Selection Schemes

In order to analyse the energy efficiency improvement of our proposed cell selection scheme, we compare it with the following schemes available in the literature:

B. Max RSRP

This scheme assigns User Equipments to base stations based on the Reference Signal Received Power (RSRP) they receive from different base stations. At the time of cell selection, UEs get associated with the base station (BS) providing highest RSRP [3]. In most cases, RSRP based association results in assigning UEs to geographically nearest base station. So, the i^{th} UE will select the k^{th} BS as its serving BS if,

$$CellID_i = arg_k max\left(RSRP_k\right)$$

All UEs within the inner white region in Figure 2 are associated with the FAP, while those outside it are associated with Macrocell. The advantage of this scheme is that UEs always get associated with BS providing highest SINR. However, disadvantage is that it might not provide UE with highest received bitrate. Additionally, low transmit power and high wall loss limits the user association in femtocell. Out of all four techniques, Max RSRP results in lowest UE association count in femtocells.

C. Max RSRP + Bias

In order to increase user association in femtocell, concept of cell biasing has been suggested. Cell biasing modifies cell selection/handover criteria in order to improve user association in femtocell by actively pushing UEs in them [4]. With cell biasing, a Range Expansion Bias (REB) of λ dB is added to RSRP from FAPs before selection of serving BS. Then,

$$CellID_i = arg_k max\left(RSRP_k + \lambda\right)$$

where λ is taken as 0 for MBS and some positive value for FAPs. This causes UEs to frequently select FAP as their serving BS. However, the newly offloaded UEs, present in the grey shaded region shown in Figure 2, are subjected to high interference from MBS. To protect their channel link quality, a fraction of bandwidth, alpha, (say α, 0 ≤ α ≤ 1) is reserved for these offloaded femtocell users while remaining bandwidth (1 − α) can be shared by both macro and fem to UEs. Advantage of this technique is that if offloads more UEs to femtocell even when they might receive high SINR from macrocell. Newly offloaded UEs, however, get benefited by additional bandwidth at femtocells. This technique proved to show improvement in system capacity compared to Max RSRP based cell selection scheme.

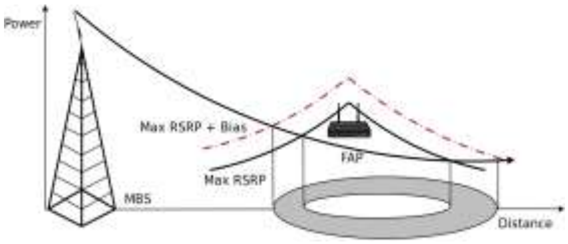

Fig. 2: ECR Vs. REB

D. Max Expected Bitrate (EE[B])

It has been previously suggested that, instead of considering biasing value, if scheduling opportunities to UEs are considered for cell selection, improved throughput performance is obtained. Authors in [6] proposed that UEs should select a base station which provides highest expected bitrate, EE[B]. The expected bitrate for UE *i*, if connected to MBS is,

$$E[B_{i,m}] = (1-\alpha)\log_2\left(1+\Gamma_{IL}^{i,m}\right)$$

and if connected to FAP *k* is,

$$E[B_{i,k}] = (1-\alpha)\log_2\left(1+\Gamma_{IL}^{i,k}\right) + \alpha\log_2\left(1+\Gamma_{IF}^{i,k}\right)$$

Let *BS* represent the set of all base stations (MBS+FAPs). UE *i* will select base station *j* as its serving base station if,

$$CellID_i = arg_j max\left\{E[B_{i,j}]; j \in \{BS\}\right\}$$

This technique shows further improvement in system capacity compared to Max RSRP + Bias based association. This technique performs optimal because it makes sure that UEs get associated with base station with highest expected received bitrate. However, calculating expected received bitrate considering total bandwidth at target base station is wrong. This might lead to suboptimal user association because received bitrate depends upon allocated bandwidth to UE rather than total bandwidth at target base station.

VI. Problem Formulation and Solution Description

Our problem focuses on energy efficient assignment of UEs to base stations considering backhaul energy and its capacity constraint. This is achieved by reducing the energy consumption of base station by allowing it to transmit at lower power. This will reduce the SINR received at UEs, however the reduction in their received bitrate can be compensated by assigning more bandwidth to them. Our proposed cell selection scheme starts with calculating the bitrate UE *u* is expected to receive in per subchannel from each base station *b* transmitting with subchannel power L_u^b as follows,

$$B_{u,b} = W*\log_2\left(1+\frac{L_u^b\Gamma_u^b}{\sum P_u^{b'}\Gamma_u^{b'}+N_0}\right)$$

Then, the number of subchannels required by UE *u* to fulfills its bitrate demand β_u is calculated as follows,

$$\Re_{u,b} = \frac{\beta_u}{B_{u,b}}$$

If the number of free subchannel at base station *b* is less than $\Re_{u,b}$ then the transmission power of base station is increased step by step until enough number of subchannels is available at base station or base station reaches to its maximum transmit power value. If base station *b* is unable to satisfy the bitrate demand of UE *u* even at maximum transmit power then it is removed from consideration. Additionally, if the free capacity of backhaul link, *B(b)*, of base station is less than $\Re_{u,b}$, then also base station *b* is removed from consideration. Let $L_{u,final}^b$ be the transmit power of base station *b* that satisfy the bitrate demand of UE *u*. Then, the energy consumption of base station *b* for UE *u* is calculated as follows,

$$E_b^{\,final} = E_b^0 + \Phi*\Re_{u,b}*L_{u,final}^b/\rho_{PA} + CL_b$$

The energy consumption of backhaul link for base station *b* (if it is a FAP) is given by,

$$BH^{final}(b) = BH_b^0 + f(B_{u,b}*\Re_{u,b})$$

Finally, we calculate the ECR value for each base station *b as* follows,

$$ECR_u^b = \frac{E_b^{\,final} + BH^{final}(b)}{B_{u,b}*\Re_{u,b}}$$

The UE *u* is assigned to base station *k* which have the highest energy efficiency or in turn the lowest ECR as follows,

$$CellID_u = arg_k \min\left(\{ECR_u^k\}; k \in \{BS\}\right)$$

Interesting thing to note that our proposed cell selection scheme does not consider the energy spent at base station and backhaul links in cell selection criteria. It rather calculated the energy spent per bit (which is the ECR) and then assign UEs to base stations having lowest ECR. This in turn improves the overall energy efficiency of the network.

VII. SIMULATION RESULTS

Our simulation scenario assumes a single MBS deployed along with low power FAPs. Both UEs and FAPs are distributed uniformly in the simulation region. FAPs are assumed to be in Always-ON state unless there are no UEs under its coverage. Snapshots are taken at discrete time intervals. For performance analysis, we have compared our proposed scheme with Max RSRP and Max Expected bitrate based cell selection scheme. All values are obtained for 95% confidence interval averaged over 60 iterations. The simulation parameters are given in Table I.

Parameter	Value
Bandwidth	10 MHz
No. of Subchannel	256
MBS Transmit Power	43 dBm
FAP Transmit Power	23 dBm
UE Transmit Power	23 dBm
UE Density	{100-500}/sq.km
FAP Density	30/sq. km
Reuse Factor (α)	1
Idle Mode Backhaul Energy	5 watt
Backhaul Capacity	{2,4,8} Mbps
Path Loss Coefficient	MBS : 2.5
	FAP: 3.5

TABLE I : SIMULATION PARAMETERS

Figure 3 represents the system capacity for all three cell selection schemes for varying UE density. As density of UEs increases, system capacity also increases. This is due to the fact that with higher number of UEs, utilization of resources at base stations also increases. This in turn results in an improvement in system capacity. Also, for fixed UE density, system capacity of all selection schemes are equal. This is because base stations assign only required number of subchannels to UEs to satisfy their bitrate demands. Hence, the received bitrate at UEs and hence the system capacity for all three cell selection schemes are almost equal.

Figure 4 represents the total energy consumption of the network for varying UE density. As expected, with an increase in UE density, the energy consumption at base stations also increases, leading to higher overall network energy consumption. Interesting thing to note that the energy consumption value for our proposed cell selection scheme is lowest among all considered schemes. This is due to use of lower transmit power at base stations and uses of energy efficiency in the

cell selection criteria. For Max RSRP and enhanced expected based cell selection, the energy

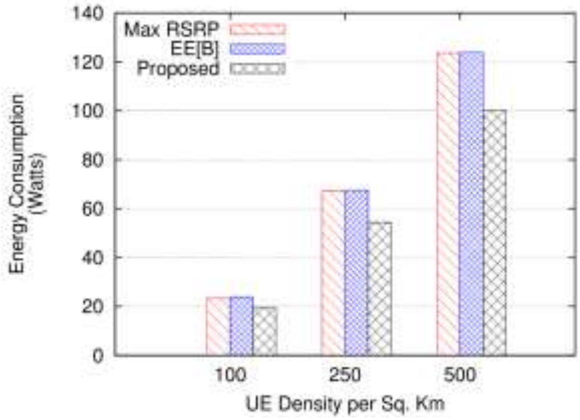

Fig. 3: System Capacity Vs. UE density

consumption is almost the same. This is because these scheme do not perform any subchannel power control and considered only received power/bitrate in the cell selection criteria.

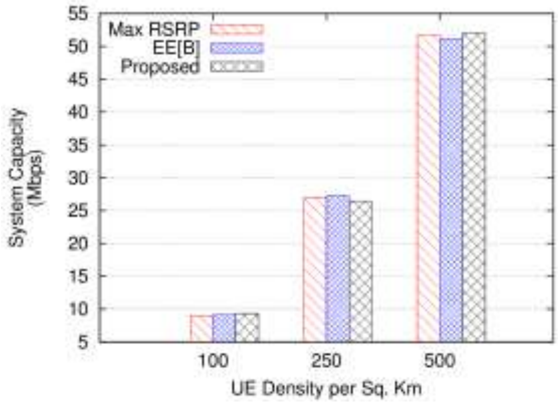

Fig. 4: Energy Consumption Vs. UE Density

Finally, in Figure 5, we present the energy efficiency performance of all cell selection schemes. As expected, our proposed scheme has the lowest ECR when compared to Max RSRP and enhanced expected bitrate based scheme. This is the direct consequence of reduction in energy consumption due to energy efficient assignment of UEs to the base stations. As UE density increases, system capacity also increases which in turn results in lower ECR value.

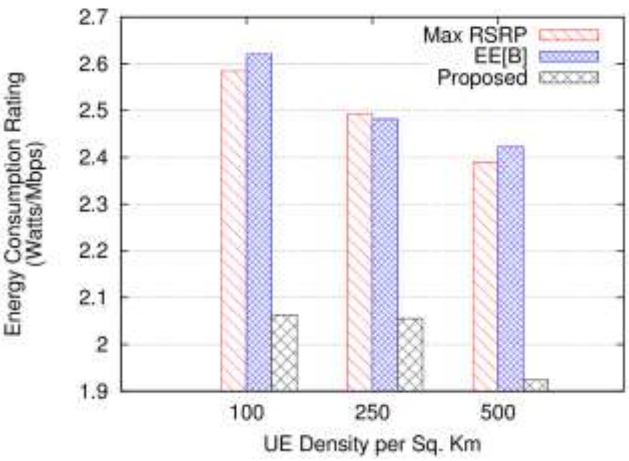

Fig. 5: ECR Vs. UE Density

VIII. CONCLUSION

Energy consumption and resource utilization in femtocell-macrocell network is greatly affected by the criteria on which mobile users get associated with femtocell base stations. RSRP and expected bitrate based association are most simple approach but they fail to energy consumption at base stations and the backhaul links. In this paper, we propose an energy efficient cell selection scheme for femtocell network with backhaul constraint. Our scheme first calculates the received bitrate and energy consumption in the network. Then, users are assigned to base stations which satisfy their bitrate demands with lowest increase in power consumption. Simulation results have verified the improvement in network performance in terms of system capacity and energy efficiency.

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